

ON THE ROLE OF SURFACE HEAT BUDGET PARAMETERS OVER THE TROPICAL INDIAN OCEAN IN RELATION TO THE SUMMER MONSOON

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ABSTRACT

This study presents the role of sea surface temperature (SST) in the Arabian Sea and Bay of Bengal, cloud motion vector winds in the Equatorial Indian Ocean, and the cold fronts in the South Africa-Malagassy region on the onset and quantum of the summer monsoon rainfall. We also examined the role of the position of the 500 MB ridge position in April along 75°E and the Southern Oscillation Index (SOI) on the monsoon rainfall.

INTRODUCTION

A fundamental consideration in global energetics is the relative roles of the tropical atmosphere and ocean in the poleward redistribution of the net radiative heat surplus received by the tropics (Hastenrath and Lamb 1980). In recent years, numerous investigators are looking into the vital role of the heat budget of the tropical oceanic areas in the formation of weather and climatic variations over different parts of the globe. Among the world oceans, the Indian Ocean shows unique characteristics because of the semiannual phenomena known as monsoons (southwest and northeast).

The summer monsoon plays a major role in the economy of an agricultural country like India as about 60-90% of the mean annual rainfall is received during this period (June-September) over most of the meteorological subdivisions. Another important factor is the onset of a monsoon, as an untimely onset can have far-reaching economic consequences for the country.

In recent years, there has been an increasing interest in fluctuations of the meteorological parameters in time scales of a few months, seasons, and years. In most of these studies, sea surface temperature (SST) has been found to play a major role. Studies by several scientists have shown that the Quasi-Biennial Oscillation and the Southern Oscillation are the only recognised cycles which exhibit a periodicity of more than 1 year.

Ramesh Kumar et al. (1986) have shown the utility of the zonal anomaly SAT over the Somalia Coast and central Indian Ocean for predicting the quantum of monsoon rainfall in various meteorological subdivisions. They also found that the appearance of the 27°C isotherm off the Somalia Coast can be used to predict the onset of the summer monsoon. In the present study we are looking at the utility of Cloud Motion Vector (CMV) wind in the equatorial Indian Ocean as well as the appearance of cold fronts in the southern hemisphere as useful predictors for the onset of the summer monsoon and the quantum of monsoon rainfall along the west coast of India. In addition, we also look at the role of the SSTs in the Arabian Sea, Bay of Bengal and the SOI and the position of the 500 MB ridge in April along 75°E. The CMV wind data from the INSAT cloud imageries form the major source of information regarding the upper air winds over the Indian Ocean.

DATA AND METHODOLOGY

In the present study, the data from the GOES and INSAT-1D satellite have been utilized to examine the cross-Equatorial flow associated with the onset of monsoons over Kerala coast for the years 1979 and 1991 along different longitude belts. The period considered here is from 16 May to 30 June, so as to cover a few weeks prior to and following the actual monsoon conditions. The monsoon onset was delayed by about 2 weeks and occurred on 12 June 1979, but it was normal in 1991 and it occurred on 2 June (the normal onset being on 1 June). The CMV wind data pertaining to the year 1979 has been extracted from the atlas of Young et al. (1980) and for the year 1991 has been obtained from the Satellite Meteorology Division, India Meteorological Department. The technique used for extraction of CMV wind data is that of Kelkar and Khanna (1986) and is as follows. The automated CMV extraction procedure requires three full resolution sectorised, navigated, and registered images of which two are visible images for time T and T + T, and the third is an infrared image at time T. The time T is generally 30 minutes. The visible channels are preferred for detecting cloud displacements as the resolution of the INSAT VHRR visible channel at sub-satellite point is 2.75 km as compared to 11 km in the infrared channel. The infrared images are used for assigning the height of the cloud. The height is calculated from the brightness temperature using the SST and assuming a standard lapse rate of 6.5°C/km. The image registration eliminates the generation of spurious CMV winds not representing the actual cloud motion. The technique is based on a pattern-matching procedure adopted to arrive at a minimum absolute difference of grey shade between corresponding pixels of the same cloud pattern of size 40 km x 40 km over a 0.5-hour interval. The wind speed and direction are obtained from the relative shifts of the center of the pattern. The CMV wind data were also subjected to a systematic quality control procedure following Yadav and Kelkar (1989). The quality control method eliminates the spurious CMVs and CMVs which does not represent the general wind flow in the study area.

The mean value of the low level winds (<3 km) derived from the CMV winds was computed for each day in the domain 2°N-2°S for different longitude belts 40°E-50°E, 50°E-60°E, 60°E-70°E, and 70°-80°E for the study period. The rainfall data for nine stations (Trivandrum, Aleppy, Cochin, Calicut, Mangalore, Panjim, Ratnagiri, Dhanau, and Bombay) were extracted from the Indian daily weather reports for the study period for both the years (1979 and 1991). Correlation between the intensity of the low level cross-Equatorial flow and the mean rainfall at nine stations along the west coast of India were examined for different lags (3, 4, and 5 days) and for different longitude belts for the years 1979 and 1991. The surface meteorological parameters needed for the present study have been extracted from the unpublished Bunker data set for the tropical Indian Ocean for the period 1948 to 1972. The quality of these parameters was thoroughly checked following Joseph (1983). The rainfall data for the period 1948 to 1972 have been extracted from Mooley and Parthasarathy (1984). The data pertaining to the SOI have been extracted from Shukla and Paolino (1983). Here the SOI refers to the difference in pressure between April and January sea level pressure at Darwin. Darwin is located near one of the nodes of the SOI. We have also used the pressure tendency rather than the actual pressure in this study following Shukla and Mooley (1987). The data on the position of the 500 MB ridge along 75°E in April for the period 1948 to 1972 have been extracted from Mooley et al. (1986).

RESULTS AND DISCUSSION

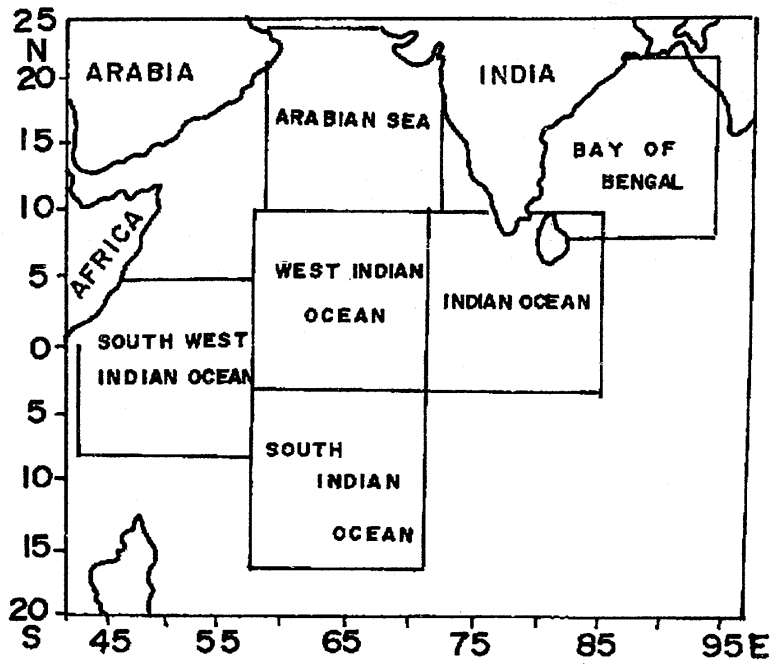


Figure 1. Map showing study areas.

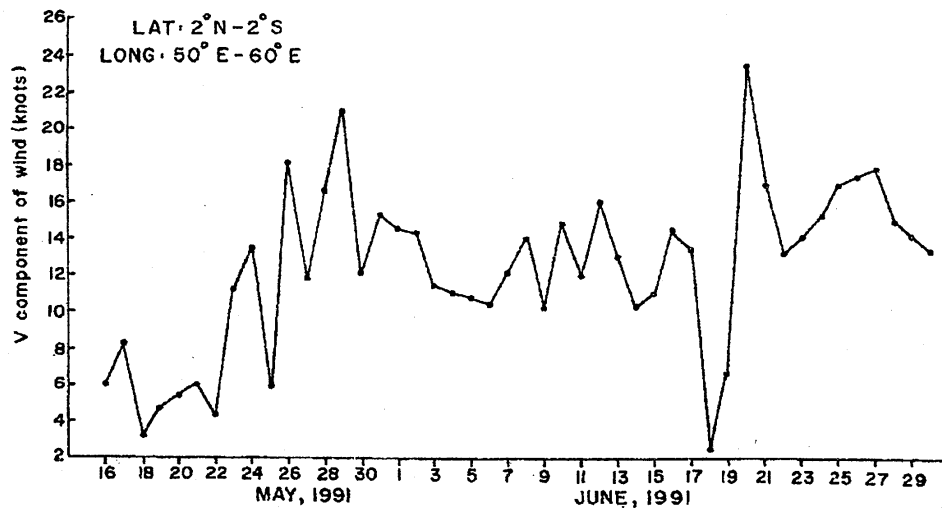


Figure 2. Cross-Equatorial flow between 40°E-50°E.

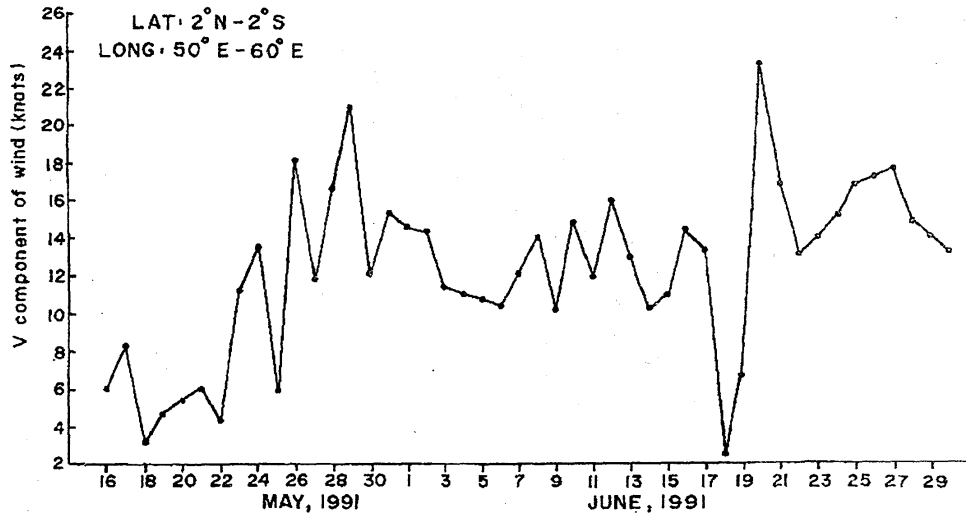


Figure 3. Same as Fig. 2 but for 50°E-60°E

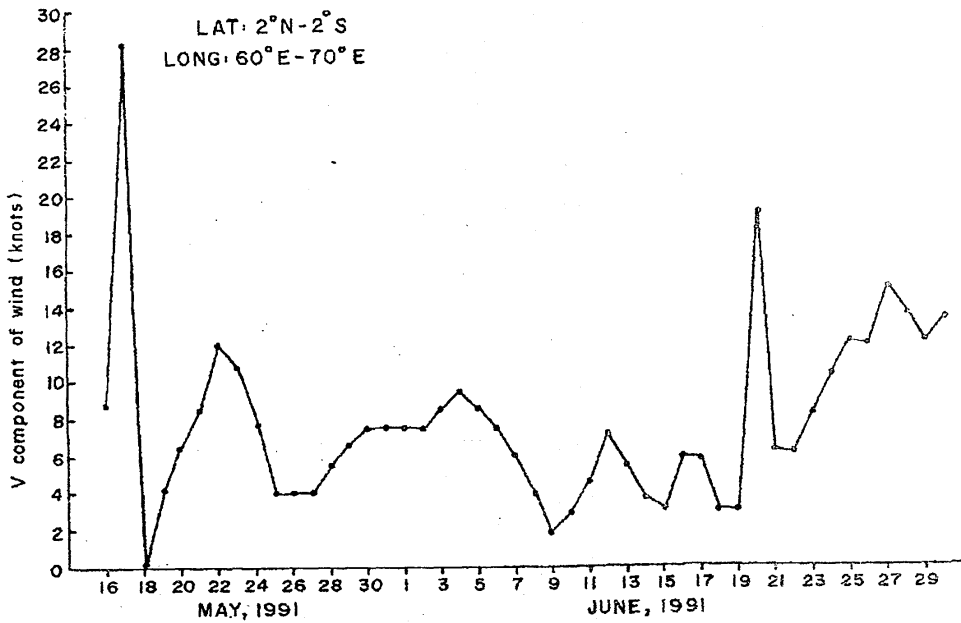


Figure 4. Same as Fig. 2 but for 60°E-70°E

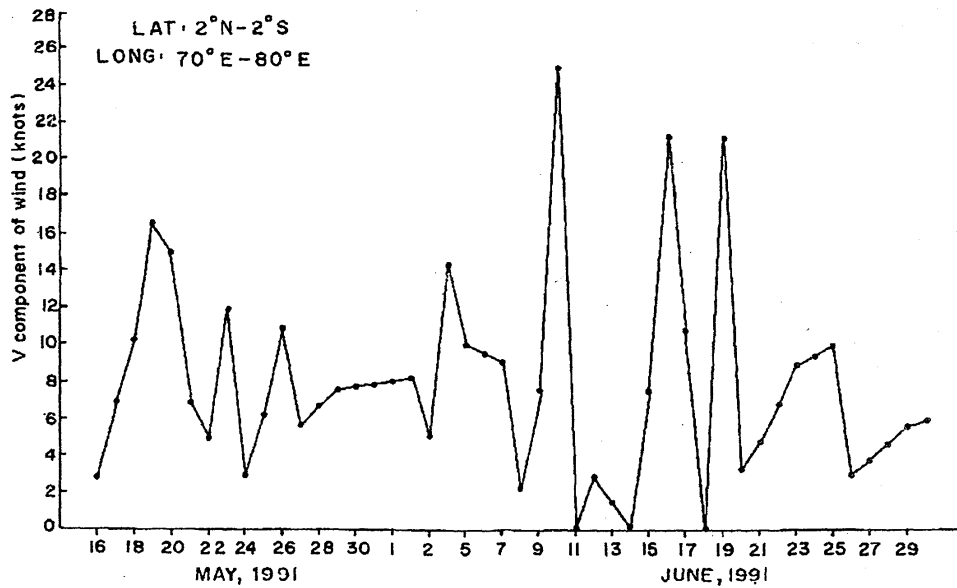


Figure 5. Same as Fig. 2 but for 70°E-8°E.

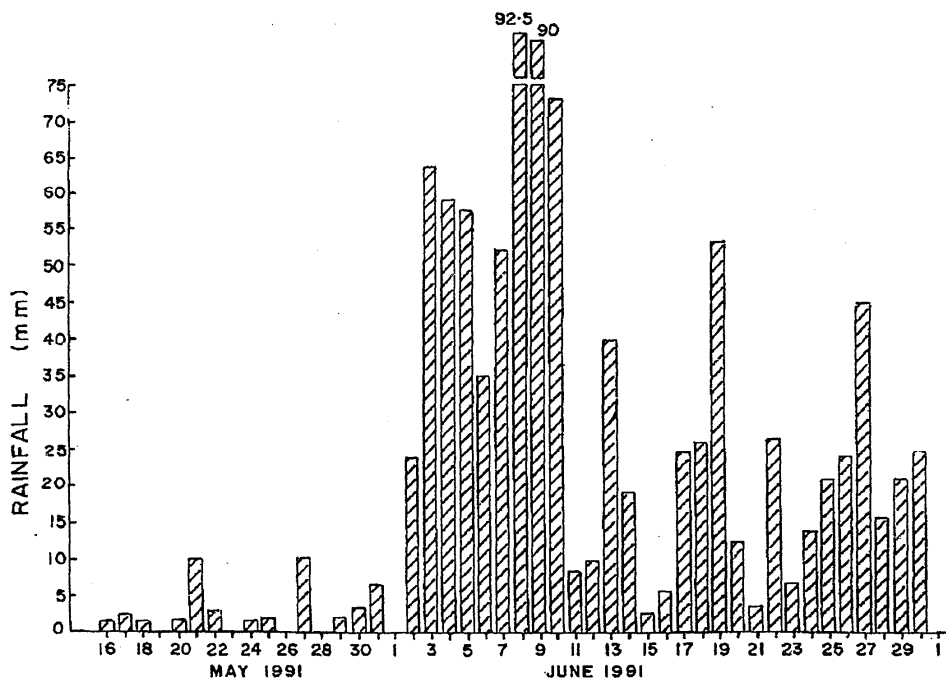


Figure 6. Time series of mean rainfall (nine stations) along west coast of India for the study period

The six regions in the tropical Indian Ocean (Fig. 1) are the Arabian Sea, Bay of Bengal, western Indian Ocean, southern Indian Ocean, southwestern Indian Ocean, and central Indian Ocean for which the CMVs are routinely collected. The low level CMV winds which are representative of the 850 MB (approximately 1.5 km) are used in the present study, and these are mainly extracted from the three sectors: 1) southwestern Indian Ocean, 2) western Indian Ocean, and 3) central Indian Ocean and between the latitudes 2°N and 2°S and between longitudes 40°E and 80°E.

The cross-Equatorial flow in the belt 40°E-50°E during the study period is shown in Fig. 2. In the case of 1991 the cross-Equatorial flow prior to the onset of the monsoon was 5 m/sec, but after the onset the flow increased to about 8 m/sec. In the case of 1979, the cross-Equatorial flow prior to the onset of the summer monsoon was 6 m/sec; but after onset it almost doubled and increased to about 12 m/sec. Fig. 3, 4, and 5 depict the cross-Equatorial flow in the different longitude belts 50°-60°E, 60°-70°E, and 70°-80°E respectively in 1991. From the figures it is obvious that there is substantial cross-Equatorial flow in the different belts but of lesser intensity than the western part. An interesting result is that the cross-Equatorial flow in the western part during the study period (16 May to 30 June) was more during the year 1979 than 1991 even though the monsoon was quite weak over the Indian subcontinent. This may be due to the low precipitable water values and weak surface winds over the Arabian Sea (Ramesh Kumar et al. (1993) than in 1991.

The time series of mean rainfall along the west coast of India for nine stations from 16 May 1991 to 30 June 1991 is shown in Fig. 6. It is significant to note that the rainfall activity prior to 2 June was weak and increased suddenly after the onset. This low amount of rainfall prior to 2 June can be due to pre-monsoon thunderstorm activity. With the establishment of low level jet and monsoon current the rainfall along the west coast stations has increased suddenly. Similar rainfall distribution was observed in the year 1979 along the west coast stations (figure not presented).

MONSOON ACTIVITY

The rainfall distribution over the Indian subcontinent in 1991 was normal to excess in 27 (80%) out of the 35 meteorological subdivisions. The onset was normal in 1991. Further, no meteorological subdivision reported scanty rainfall. The onset of the summer monsoon was delayed by about 2 weeks in 1979, and the rainfall was deficient in most of the meteorological subdivisions and normal to excess in only a few.

An analysis of the satellite-derived SST for the years 1979 and 1991 has shown that the SSTs were in general higher in the western Arabian Sea in 1979 than in 1991 during the monsoon season. This may be due to the weak surface winds off the Somalia and Arabian Coasts. The SSTs off the Somalia Coast started decreasing with the establishment of the low level jet in both years.

We have tried to correlate the intensity of the cross-Equatorial flow in the different longitude belts with the summer monsoon rainfall in nine stations along the west coast of India for 1979 and 1991 after the establishment of the monsoon. In the present study we have used the intensity of low level winds in the belt 40°E-50°E as the representative of the low level jet flow. We have found positive and significant correlation between the

cross-Equatorial flow in the belt 40°E-50°E and the monsoon rainfall in nine stations along the west coast of India. We feel that the high pressure in the South Africa-Malagassy region will channel the surge of cold air into the Mozambique Channel which will further push the low level winds into the northern hemisphere, especially along the Somalia Coast. An analysis of the cold fronts and high pressure systems in this region for the years 1979 and 1991 for the study period has shown that the cross-Equatorial flow increases about 2 to 3 days after the formation of these systems. Hence they can be thought of as useful predictors for the monsoon activity at least 5 to 7 days in advance.

Table 1. Correlation coefficients between different meteorological parameters in the Arabian Sea.

Parameters	MSQ-67	MSQ-66	MSQ-65	MSQ-29
SST & AT	0.89*	0.93*	0.85*	0.86*
SST & CL	-0.24	0.10	0.02	-0.19
SST & WS	-0.31*	0.04	-0.09	-0.41*
SST & SLP	-0.05	-0.48*	-0.22	-0.13
WS & SLP	-0.73*	-0.75*	-0.81*	-0.51*
WS & CL	0.63*	0.86*	0.78*	0.57*
SLP & CL	-0.73*	-0.75*	-0.67*	-0.35*

*Means significant at 0.1% level.

From the correlation between the surface meteorological parameters in the Arabian Sea (Table 1) it is obvious that the SST and air temperature (AT) are positively and significantly correlated in all the regions. The wind speed (WS) and the cloudiness (CL) are also positively and significantly correlated in all the regions in the Arabian Sea. Further, the WS and the CL were found to be negatively and significantly correlated with the sea level pressure (SLP) values. It was also found that there was no significant relationship between the CL and WS with the SST in the Arabian Sea region.

Table 2. Correlation between seasonal SSTs, monsoon rainfall, 500 MB ridge, and SOI.

Parameter	Monsoon rainfall	500 MB ridge	SOI
PMSST (MSQ 31)	0.41 ³	0.36 ²	-0.11
WSST (MSQ 64)	0.47 ⁴	0.36 ³	-0.29 ¹
PMSST (MSQ 65)	0.40 ³	0.39 ³	-0.35 ²
PMSST (MSQ 67)	0.41 ³	0.30 ¹	-0.20

Where PMSST means pre-monsoon SST, and WSST means winter SST.

Table 2 gives the relationship between the pre-monsoon SSTs (PMSST) in the eastern Arabian Sea (MSQ 65), western Arabian Sea (MSQ 67), and the Somalia Coast region (MSQ 31) as well as the winter SST (WSST) in the Bay of Bengal (MSQ 64) with the Monsoon rainfall, SOI and the 500 MB ridge position. The analysis shows that the PMSSTs

of the above three areas in the Arabian Sea, namely the western Arabian Sea, eastern Arabian Sea, and Somalia Coast region and the WSST in the Bay of Bengal region are positively and significantly correlated with the monsoon rainfall and hence can be thought of useful predictors for the summer monsoon rainfall. Further, it was found that the above SSTs were found to be positively and significantly correlated with the mid-tropospheric circulation (position of the 500 MB ridge in April along 75°E). The SOI was negatively and significantly correlated with the PMSST of the eastern Arabian Sea (MSQ 65) and WSST of the Bay of Bengal region (MSQ 64).

We have also examined the relationship between subdivisional monsoon rainfall over the 35 meteorological subdivisions and the SOI. It was found that SOI is negatively and significantly correlated at the 5% level or above for 15 meteorological subdivisions, mainly over the area north of 12°N and west of 85°E, and at the 1% level and above for eight of these subdivisions.

CONCLUSIONS

1. The cross-Equatorial flow in the western part and the high pressure systems in the southern hemisphere can be thought of as useful predictors for predicting the onset and quantum of monsoon rainfall.
2. The PMSSTs in the eastern Arabian Sea and western Arabian Sea and off the Somalia Coast and the WSST in the Bay of Bengal region were found to be positively and significantly correlated with the monsoon rainfall.
3. The relationship between subdivisional monsoon rainfall and the SOI is negatively and significantly correlated at the 5% level or above for 15 meteorological subdivisions, mainly over the area north of 12°N and west of 85°E, and at the 1% level and above for eight of these subdivisions.
4. An analysis of the correlation coefficients of the various surface meteorological parameters in the Arabian Sea has shown that SST and AT are positively and significantly correlated (at 0.1% level). Further, the WS and CL were negatively and significantly correlated with the SLP over the Arabian Sea (at 0.1% level).

We propose to study the role of convection over the tropical Indian Ocean on the monsoon rainfall over the Indian subcontinent using the outgoing long-wave radiation, SST, and Precipitable Water using data from INSAT and NOAA and DMSP satellites.

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REFERENCES

- Hastenrath, S. and Lamb, P.J. (1980). On the heat budget of the hydrosphere and atmosphere in the Indian Ocean. **J. Phys. Oceanogr.**, 10: 694-708.
- Joseph, P.V. (1983). Interannual variability of Indian summer monsoon rainfall. Unpubl. Ph.D. thesis, Poona University, 106 p.
- Kelkar, R.R., and Khanna, P.N. (1986). Automated extraction of cloud motion vectors from INSAT-1B imagery. **Mausam**, 37: 495-500.
- Mooley, D.A. and Parthasarthy, B. (1984). Fluctuations in all India summer monsoon rainfall during 1871-1978. **Clim. Change**, 6: 287-301.
- Mooley, D.A., Parthasarthy, B. and Pant, G.B. (1986). Relationship between all India summer monsoon rainfall and location of the ridge at 500 MB level along 75°E. **J. Clim. Appl. Meteorology**, 21: 633-640.
- Ramesh Kumar, M.R., Sathyendranath, S., Viswambharan, N.K., and Gangadhara Rao, L.V. (1986). Sea surface temperature variability over the north Indian Ocean - A study of two contrasting monsoon seasons. Proceedings of Indian Academy of Sciences (Earth and Planetary Sciences), 95: 435-446.
- Ramesh Kumar, M.R., Muraleedharan, P.M. and Sathe, P.V. (1993). Precipitable water over the tropical Indian Ocean from Nimbus 7 SMMR data - A case study. **Boundary-Layer Meteorol.**, 66: 325-330.
- Shukla, J. and Paolino, D.A. (1983). The Southern Oscillation Index and longrange forecasting of the summer monsoon rainfall over India. **Monthly Weather Rev.**, 111: 695-703.
- Shukla, J. and Mooley, D.A. (1987). Empirical prediction of the summer monsoon rainfall over India. **Monthly Weather Rev.**, 115: 695-703.
- Yadav, B.R. and Kelkar, R.R. (1989). Low level wind flow over the Indian Ocean during the onset of monsoon - 1987. **Mausam**, 40: 323-328.
- Young, J.A., Virji, H. Wylie, D.P and Lo, C. (1980). Summer monsoon windsets from geostationary satellite data, summer MONEX; 1 May-31 July 1979. Space Sci. and Eng. Centre and Dept. of Meteorol., Univ. of Wisconsin, Madison, U.S.A.